Seasonal presence of cetaceans and ambient noise levels in polar waters of the North Atlantic

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Abstract: In 2009 two calibrated acoustic recorders were deployed in polar waters of the North Atlantic to study the seasonal occurrence of blue, fin, and sperm whales and to assess current ambient noise levels. Sounds from these cetaceans were recorded at both locations in most months of the year. During the summer months, seismic airguns associated with oil and gas exploration were audible for weeks at a time and dominated low frequency noise levels. Noise levels might further increase in the future as the receding sea ice enables extended human use of the area.

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1. Introduction

The Arctic is a unique and species-rich environment, and remains one of the least-studied and least-understood ecosystems on earth. This fragile area is experiencing rapid changes: Polar amplification of global warming is predicted to result in a sea-ice-free Arctic in 30–40 years (Wang and Overland, 2009; Serreze and Barry, 2011). Quantifying the inevitable ecosystem-wide effects of climate change in the Arctic will require continuous long-term observations, but such monitoring is logistically difficult and expensive.

Passive acoustic long-term recording offers the possibility of continuously monitoring inaccessible areas like the Arctic at relatively low cost and without dependence on weather conditions. Acoustic monitoring can provide valuable information on changes in the Arctic marine environment, including the seasonal distribution and abundance of vocally active marine mammals using these waters. Whales and seals play an important role in this polar ecosystem, however, comprehensive information on their distribution and habitat use in Arctic waters is scant, but will be necessary if climate-related effects on these species are to be studied (Moore and Huntington, 2008). Understanding ambient sound in this environment is also important as man-made noise—which adversely affects marine mammals (e.g., Rolland *et al.*, 2012)—is expected to increase as sea-ice recedes. The goals of this pilot study were to assess baseline information on the seasonal presence of cetaceans and current ambient noise levels in polar waters of the North Atlantic.

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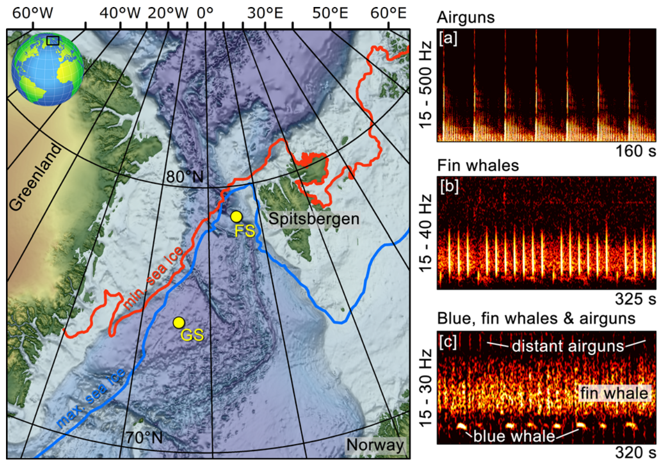

Fig. 1. (Color online) (Left panel) Map of the study area including locations of the Fram Strait (FS) and Greenland Sea (GS) hydrophones, as well as minimum (September 9, 2009) and maximum (March 31, 2010) sea ice extents during the deployment period. Bathymetry map based on 2 min gridded global relief data (ETOPO2v2, 2006) provided by the NOAA National Geophysical Data Center, Boulder, CO. Ice data were provided by the U.S. National Ice Center, Suitland, MD. (Right panel) Spectrograms of recorded (a) airgun sounds, (b) nearby fin whale calls, and (c) blue whale calls, distant fin whale calls, and distant airgun sounds.

2. Materials and methods

2.1 Instrumentation and deployment location

Two autonomous underwater hydrophones developed by Oregon State University and NOAA Pacific Marine Environmental Laboratory were deployed on moorings in the Fram Strait (FS) and Greenland Sea (GS). Details on the deployments are presented in Fig. 1 and Table 1. The acoustic signals were continuously digitized from July 2009 to June 2010 at 2000 Hz sampling rate and 16 bit resolution with a low-pass filter cut-off frequency of 840 Hz. All electronic components (pre-amplifier, etc.) were calibrated prior to and after deployment. The hydrophone used was a model ITC-1032 (International Transducer Corp., Santa Barbara, CA) with a sensitivity of -194 dB re. 1 V/μPa. A calibration data sheet for the hydrophone was provided by the manufacturer. To utilize the full 16 bit dynamic range of the data logger, the signal was pre-whitened by the pre-amplifier with a frequency-dependent gain. The noise floor of each system is shown in Figs. 3(a) and 3(b).

2.2 Sound analysis

This pilot study focused on three cetaceans, sperm whales (*Physeter macrocephalus*), which are listed as a vulnerable species, and endangered blue (*Balaenoptera musculus*), and fin (*Balaenoptera physalus*) whales (IUCN, 2011). The data were examined for the

Table 1. Information on autonomous hydrophone deployments in the Fram Strait and Greenland Sea.[a]

Date of data collection	Location	Coordinates	Water depth (m)	Hydrophone depth (m)[b]	Mooring number
July 15, 2009–June 30, 2010	Fram Strait	78° 50′ N, 05° 29′ E	2549	488	F22
July 10, 2009–June 20, 2010	Greenland Sea	74° 56′ N, 04° 37′ W	3540	480	JP37

[a]Instruments were deployed on moorings maintained by the Alfred Wegener Institute for Polar and Marine Research, Germany.
[b]Hydrophone depth is presented in meters below sea surface.

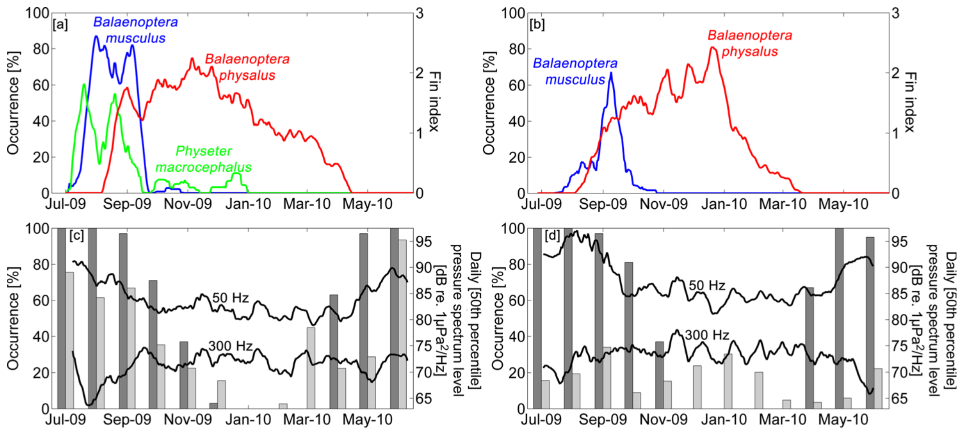

Fig. 2. (Color online) Seasonal pattern of marine mammal calls in (a) the FS and (b) the GS. The blue and sperm whale curve represents occurrence in percent hours per day. Fin whale calling activity is represented by a relative measure, the fin index (cumulative energy in the fin whale frequency band; secondary *y*-axis). The analyst noted only a single instance of sperm whale vocalizations in the GS on February 5, 2010 not shown in the graph. Lower panels show occurrence (percent hours per month) of airgun pulses (dark bars) and ship noise (light bars) in the FS (c) and GS (d). Superimposed are daily median (50th percentile) 50 and 300 Hz spectrum levels. All line curves are smoothed with a 7 day moving average. Tick marks on the *x*-axis indicate the 15th of each month.

presence of sounds produced by these species, as well as anthropogenic sources (seismic airguns and ships). An automatic detection algorithm was used to screen the data sets for blue whales and seismic airgun pulses (Nieukirk *et al.*, 2012). Fin whale sounds were identified by calculating the long-term spectrogram for each location and then deriving a relative estimate of fin whale calling, the fin index (cumulative energy in the fin whale frequency band), from these spectrogram data (Nieukirk *et al.*, 2012). This technique was used because during peak calling season, overlapping fin whale calls resulted in a continuous noise band, which made it impossible to identify individual calls [Fig. 1(c)]. The presence of sperm whales, as well as noise generated by nearby ships was determined by examining consecutive 1 h sections of long-term spectrum data, derived from spectra calculated with 1 Hz frequency resolution and averaged over 60 s, using the software package TRITON (available at http://cetus.ucsd.edu/). Sperm whale click frequencies are centered higher than the frequency band recorded here, but their spectrum extends to sufficiently low frequencies that they were readily detectable. Noise levels associated with shipping varied significantly during the study. Due to time constraints, noise associated with shipping was simply identified as either present or absent in each hour of data. In all cases the analyst was conservative in the identification of the target signals, and thus the reported data represent minimum rates. Ambient noise levels for the frequency band 15–840 Hz were calculated for the two deployment locations via methods similar to those described by McDonald *et al.* (2006) and McDonald *et al.* (2008). Spectral averages with a 1 Hz frequency resolution were calculated for consecutive 200 s segments of data with no overlap [fast Fourier transform (FFT) size: 2000 samples (1 s), Hann window]. This resulted in ∼150 000 spectral averages calculated for each data set, which were then used to derive percentiles of low-frequency noise level distributions.

3. Results

Sounds from marine mammals were recorded seasonally at both locations [Figs. 2(a) and 2(b)]. Sperm whale echolocation clicks were recorded in the FS from July to January, but were documented only once (February 5, 2010) in the GS. Blue whale

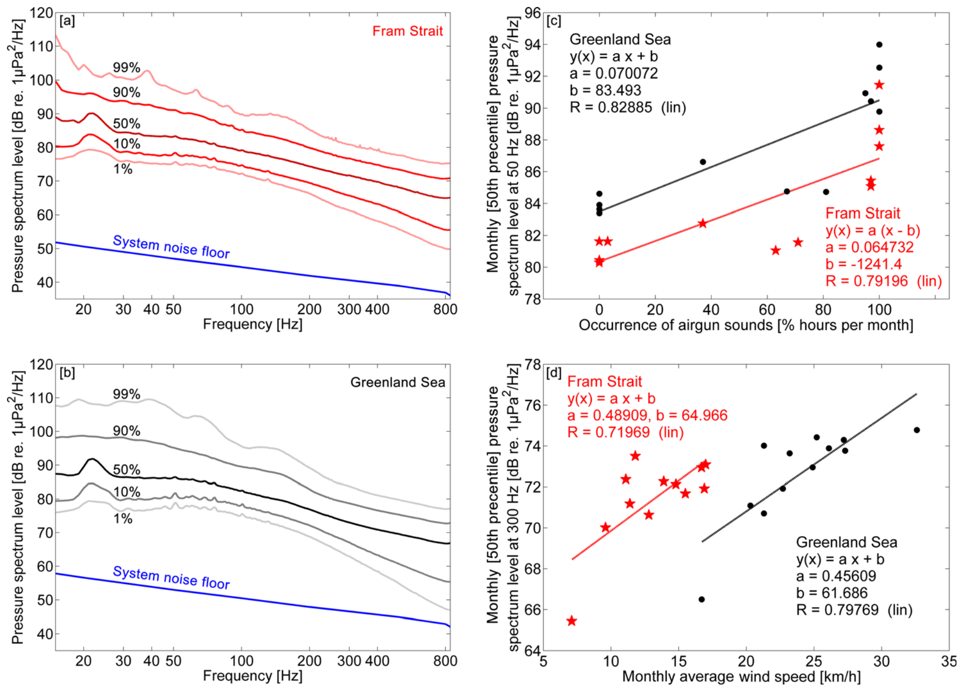

Fig. 3. (Color online) (Left panel) Low-frequency noise level distributions (1st, 10th 50th, 90th, and 99th percentiles) for (a) the FS and (b) GS for the entire deployment duration July 2009–June 2010. The noise floor differs because of different gain settings (FS + 12 dB; GS + 6 dB). Note the pronounced "bump" in the curve centered at 22 Hz, which reflects the contribution of fin whale calls to noise levels. (Right panel) (c) Correlation between occurrence of airgun sounds and monthly median (50th percentile) pressure spectrum level at 50 Hz. (d) Correlation between monthly average wind speed and monthly median (50th percentile) pressure spectrum level at 300 Hz. Monthly average wind speed recorded at weather station Ny-Ålesund (78.91°N–11.93°E; ~140 km east of FS hydrophone) and Jan Mayen (70.93°N–8.66°W; ~440 km south of GS hydrophone). Weather station Ny-Ålesund did not report data December 19, 2009 to January 13, 2010. Data from http://www.tutiempo.net/en/.

vocalizations were recorded on both hydrophones from August to November, but more often, and earlier and later in the season, in the FS. Fin whales were the most prevalent species recorded at both sites: Calls were recorded in August, throughout the fall and winter, and into April. Peak calling occurred earlier in the FS (early December) than the GS (early January). During the summer months (May–September), airgun signals were audible almost every hour per month at both deployment locations [Figs. 2(c) and 2(d)]. Ship noise was also prevalent during the summer at the FS location. In the central GS ships were recorded year-round; however, overall levels were comparatively low most likely because ships were not passing close to the hydrophone.

Two frequency bands were chosen for further analysis: 50 Hz, which reflects noise generated by anthropogenic activities (especially airgun signals), and 300 Hz, which reflects noise associated with ocean surface wind (Andrew *et al.*, 2002). Daily median 50 and 300 Hz spectrum levels [Figs. 2(c) and 2(d)] indicate a seasonal pattern, with comparatively higher levels at lower frequencies in summer when anthropogenic activities in both areas peaked. At both locations, monthly median spectrum levels at 50 Hz were significantly correlated with the occurrence of airgun sounds [Fig. 3(c)], and monthly median spectrum levels at 300 Hz were significantly correlated with average wind speeds [Fig. 3(d)]. Observed ambient noise levels were generally higher in the GS than in the FS [Figs. 2(c), 2(d), 3(a), and 3(b)] and are likely related to generally higher wind speeds in the area, as well as closer distance to seismic exploration sites.

Fin whales were a major biological contributor to the noise levels in the 19–24 Hz frequency band at both deployment locations [see Figs. 3(a) and 3(b)].

4. Discussion

Cetaceans were present in the study area during most months of the year. Both sites were ice-free and are thus suitable habitats for non-pagophilic species year-round. Øien (2009) analyzed data from visual surveys collected 1995–2001, and although the FS was surveyed every year, no sperm whales were sighted in this area (Fig. 4 in Øien, 2009), a finding that is contrary to the results of this acoustic study. The number of blue whales in this area has been estimated to be in the hundreds (Pike *et al.*, 2009) and the results of the acoustic analysis suggests that their presence is limited to a brief period in late summer/early fall. Fin whales were the most prevalent species recorded at both sites, which is not surprising given the population estimate (>6000; Øien, 2009) for this region. Calls were recorded in August, throughout the fall and winter, and into April. These results are similar to those reported by Moore *et al.* (2012) from a site east of the FS hydrophone.

Observed seasonal variations in ambient noise levels were caused by anthropogenic activities, ocean surface wind, and calling whales. A comparison of median daily spectrum levels throughout the seasons suggest: (a) anthropogenic activities (mainly seismic exploration) were a predominant noise source during the summer months and raised the median daily 50 Hz spectrum level up to 20 dB re. 1 μPa^2/Hz, (b) severe winter storms raised median daily spectrum levels at the same frequency by up to 12 dB re. 1 μPa^2/Hz, and (c) fin whales significantly contributed to the overall sound budget and raised median daily 22 Hz spectrum levels during the peak calling season by as much as 10 dB re. 1 μPa^2/Hz. Deriving natural (excluding man-made sounds) ambient sound levels at frequencies less than 100 Hz during the summer months was difficult, as reverberation effects associated with the propagation of airgun signals (see also Guerra *et al.*, 2011) often caused a continuous series of transient sounds [Fig. 1(a)]. The minimum distance to the ice edge throughout the deployment period was $\sim$70 km (see map in Fig. 1) and noise generated by ice presumably contributed little to the overall noise budgets (Diachok and Winokur, 1974).

A comparison with noise levels recorded in the GS during a 10 month period in 1972–1973 (McGrath, 1976) revealed that historic and current noise levels in the winter months differ little. However, McGrath (1976) stated that there were no significant seasonal changes in the 1/3 octave band with center frequency 50 Hz, which is contrary to the results presented here where we observed increased ambient noise levels associated with seismic activities during the summer months. However, the degree of seismic oil and gas exploration can vary substantially between years, and there is a possibility that the noise levels reported by McGrath (1976) were recorded during a period with low anthropogenic activity. More data covering multiple years are needed to evaluate year-to-year variability in ambient noise levels.

5. Conclusion

These data will help to evaluate future changes in this sensitive Arctic environment. Anthropogenic activities in the study area will most likely increase in the future. Receding sea-ice in the Arctic Ocean will allow commercial ships to reduce transit time significantly between northern Europe and Asia by taking an Arctic route, and rich oil and gas deposits located on the eastern Greenland continental shelf are likely to be exploited in the near future. While the peak of sperm and blue whale calling activity does already temporally overlap the peak of anthropogenic noise in the study area, fin whales might be the species most affected by future expansion of anthropogenic activities into the winter months.

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